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APPLICATION OF ESTIMATION THEORY TO ACOUSTIC SIGNAL PROCESSING

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Application of Estimation Theory to Acoustic Signal Processing

Abstract

In this thesis four acoustic measurement situations are studied. It is found that estimation theory can be applied resulting in acoustic signal processing methods.

In part I of the thesis estimation of the reverberation decay function is considered. An estimation method is analysed and developed.

Estimation of amplitude and phase is studied in part II. It is found that the implementation of a discrete time method becomes essentially simplified if the sampling rate is chosen to be four times the frequency of the exciting sine signal.

The third part, III, describes the measurement of power attenuation. A discrete time estimation method is found which on certain assumptions gives efficient estimates. The technique is to introduce an idle time interval at the estimator. An implementation is made and introductory measurements presented.

The task of estimating environmental industrial noise is treated in part IV. The aim is to estimate the equivalent sound pressure level. In order to effectively use the estimation time a measurement strategy is proposed which uses the fact that the sound source often can be modelled into a number of stationary random processes.

Key words

Estimation Theory, Signal Processing, Measurement, Acoustics, Reverberation, Amplitude function, Phase function, Sound propagation, Environmental industrial noise.

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May 5 1981

**APPLICATION OF ESTIMATION THEORY
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Per Eriksson

LUND 1981

To my dear ones,
my father Erik,
my mother Rut,
my wife Rosmarie,
and my children
Sofie, Paula, Charlotta and
with most sincere gratitude.



APPLICATION OF ESTIMATION THEORY TO ACOUSTIC SIGNAL PROCESSING

The thesis comprises this summary and the following four papers:

- I. Measurement of Reverberation Decay Function and Acoustical Impulse Response Using Maximum-length Sequences and FFT.
Lund Institute of Technology,
Telecommunication Theory, Technical Report TR-149,
Department of Building Acoustics, TVBA 3005,
Lund 1981.
- II. On Estimation of the Amplitude and the Phase Function.
Lund Institute of Technology,
Telecommunication Theory, Technical Report TR-148,
Lund 1981.
- III. Estimation of Power Attenuation of a Noisy Acoustic Channel.
Lund Institute of Technology,
Department of Building Acoustics, TVBA-3007,
Telecommunication Theory, Technical Report TR-150,
Lund 1981.
- IV. On Estimation of Environmental Industrial Noise.
Co-author Sven Lindblad
Lund Institute of Technology,
Department of Building Acoustics, TVBA-3006,
Lund 1981.

INTRODUCTION

Estimation theory deals with the problem of finding a signal in noise. The signal may, according to [1], either be a random process whose statistical characteristics contain parameters or a deterministic signal known except for some parameters. The object is to estimate these parameters.

The theory has been applied in many areas, e.g. in communications, automatic control and in measurement technique. The estimation problem that arises when a signal is fed into a linear system and disturbed by additive noise, is well established in literature.

This thesis deals with estimation theory in acoustic applications. An acoustic channel can with a high degree of accuracy be modelled into a linear system. In acoustic measurements the background noise often causes a problem resulting in low signal-to-noise ratio. Such a situation is however well suited for the application of estimation theory since the background noise is an additive disturbance and the channel linear.

Another way to cope with the background noise is by increasing the power of the exciting signal. This power, however, is constrained because an increased input power requires a more powerful exciting device, i.e. in general a more expensive and larger device. Furthermore an increased power gives an increased sound level that might not be tolerated. This means that a signal processing method which increases the signal-to-noise ratio without increasing the input power is most valuable.

In this thesis such signal processing methods are studied. The first two parts are devoted to estimation of impulse response and transfer function respectively, of a linear time-invariant system. Since such a system is completely described by its impulse response or equivalent transfer function, the estimation methods described in parts I and II give the details of the acoustic channel under consideration. The assumption time-invariant is in general valid for an acoustic indoor channel.

When dealing with acoustic applications one is not always interested in details of the transfer function. Measurements are made for a number of frequency bands and the aim is to estimate a power over each frequency band. In part III this latter measurement problem is treated. It is pointed out that the method presented may not only be applied to indoor measurements but also to outdoor acoustic measurements. This is due to the fact that this method, appropriately used, is not affected by the time-variance of an outdoor acoustic channel. In part IV the problem of estimating time-varying outdoor industrial noise is studied.

REVERBERATION DECAY FUNCTION

In acoustics the reverberation decay function is a central concept. The problem of estimating this function is considered in part I. A method suggested in [2] is studied. This method, in which the impulse response is estimated using a binary maximum-length sequence as exciting signal, is analysed and developed. The estimate of the impulse response is found by cross-correlating the input and output signal using an FFT algorithm. The estimate of the impulse response is then used to calculate an estimate of the reverberation decay function. The method is easy to use and gives high signal-to-noise ratios. Estimated decay functions from practical measurements are also presented in part I.

THE AMPLITUDE AND THE PHASE FUNCTION

In some acoustic applications one wants to find the amplitude and the phase function with a high degree of accuracy. In part II an analog time and a discrete time method, that simultaneously estimate amplitude and phase, are considered. These methods, which result in very high signal-to-noise ratios, use a sine signal as exciting signal and measure the amplitude and the phase func-

tion at one frequency at a time. The analog method is a commonly used technique in estimation theory, [1]. The methods are analysed and shown to give equivalent estimates. It is shown that the discrete time method becomes essentially simplified if the sampling rate is chosen to be four times the frequency of the exciting sine signal.

POWER ATTENUATION

In several acoustic applications a power attenuation has to be estimated, e.g. in the measuring of sound propagation, including sound barriers and in sound and vibration isolation measurements. In part III the task of estimating attenuation of a noisy acoustic channel is studied. A technique, suggested in [3], that uses on-off modulation of the exciting signal is analysed and developed. A discrete time method is found which on certain assumptions gives efficient estimates of signal power and background noise power. The technique is to introduce an idle time interval at the estimator.

An implementation is made and an outline of the design is presented. Introductory measurements using this realization are also given.

ENVIRONMENTAL INDUSTRIAL NOISE

The task of estimating outdoor industrial noise is considered in part IV. The noise from industries fluctuates, partly because each individual sound source gives varying sound power and partly because of the complex on-off pattern for these sources. The attenuation of the sound path, i.e. the channel, also varies strongly. The quantity to be estimated is the equivalent sound pressure level. In order to effectively use the estimation time a measurement strategy is proposed. This strategy uses the fact that an industry considered as sound

source often can be modelled into one or more stationary random processes. The properties of the channel are also taken into account.

It is also pointed out that the method presented in part III may assist estimation of environmental industrial noise.

SIGNAL PROCESSING IN ACOUSTICS

In this thesis four acoustic measurement situations have been studied. It is found that estimation theory can be applied giving acoustic signal processing methods. These methods can also be used in other applications. Furthermore there are several similar acoustic measurements that are suitable for application of estimation theory and modern signal processing techniques. Some of the signal processing methods generate new or extended applications, e.g. measurement of sound propagation over very large distances.

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